

AD-A172 367

2

MTL TR 86-29

AD

EVALUATION OF EPOXY COMPOSITES USING PHOTOACOUSTIC FOURIER TRANSFORM INFRARED SPECTROSCOPY

JAMES M. SLOAN

POLYMER RESEARCH DIVISION

July 1986

Approved for public release; distribution unlimited.

DTIC FILE COPY



US ARMY
LABORATORY COMMAND
MATERIALS TECHNOLOGY
LABORATORY

DTIC
ELECTE
SEP 29 1986
E

U.S. ARMY MATERIALS TECHNOLOGY LABORATORY
Watertown, Massachusetts 02172-0001

86 9 29 065

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

Mention of any trade names or manufacturers in this report shall not be construed as advertising nor as an official indorsement or approval of such products or companies by the United States Government.

DISPOSITION INSTRUCTIONS

Destroy this report when it is no longer needed.
Do not return it to the originator.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER MTL TR 86-29	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EVALUATION OF EPOXY COMPOSITES USING PHOTOACOUSTIC FOURIER TRANSFORM INFRARED SPECTROSCOPY		5. TYPE OF REPORT & PERIOD COVERED Final Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) James M. Sloan		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Materials Technology Laboratory Watertown, Massachusetts 02172-0001 ATTN: SLCMT-OMP		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS D/A Project: 1T161101A91A
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Laboratory Command 2800 Powder Mill Road Adelphi, MD 20783-1145		12. REPORT DATE July 1986
		13. NUMBER OF PAGES 8
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Composite materials Photoacoustics Epoxy resins Fourier spectroscopy Infrared spectroscopy Fiber-reinforced composites		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (SEE REVERSE)		

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

Block No. 20

ABSTRACT

Fourier transform infrared spectroscopy (FT-IR) using a photoacoustic sampling cell has been used to obtain high quality infrared spectra of various fiber-reinforced epoxy composites and the corresponding resin matrixes.

Photoacoustic spectroscopy (PAS) offers the advantages of having little or no sample preparation for high quality spectra to be obtained and no alignment of the infrared incident beam is necessary. This makes PAS an ideal sampling method for ~~in-field~~ testing of composite laminates. The spectra revealed information on the degree of cure of the resin system by monitoring the $915/\text{cm}^{-1}$ absorption band and the type of reinforcement material used (glass or Kevlar).

Accession For	
NTIS GNA&I	<input checked="checked" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

INTRODUCTION

Fiber-reinforced epoxy resin composite systems are currently in use in military structure applications where their increased materials strength-to-weight ratio advantage can be utilized. Applications include bridging structures, weapon components, and aircraft components. While engineering applications of composite materials have advanced very rapidly in recent years, nondestructive testing methods for these materials have not progressed as rapidly. An effort has been made at MTL to develop a nondestructive method for monitoring the degree of cure in fiber-reinforced epoxy composite laminates.

In recent years, a different type of spectroscopic technique known as photoacoustic spectroscopy (PAS) has been found very useful for the study of spectra of certain types of samples.¹ PAS employs the photoacoustic effect in which the absorption of modulated electromagnetic radiation is converted into thermal energy by nonradiative processes. The thermal energy is then transferred to the surrounding gas and produces a pressure wave or acoustic wave in the cell. This acoustic wave is then detected by a microphone.

The strength of the PAS signal (I_{PAS}) is the product of the number of photons incident on the sample and the energy per photon and a function of the thermal diffusivity. The thermal diffusivity depends on the particular modulated frequency of the interferometer incident on the sample. The PAS signal would, therefore, be larger for higher frequencies than for lower frequencies if the number of photons incident in the sample remained constant. Thus, early spectroscopic work performed using the PAS technique was primarily directed toward the UV - visible region of the electromagnetic spectrum.

Buse and Bullemer² were the first investigators to employ this technique with a commercial Fourier transform infrared spectrometer. The authors compared normal infrared spectra of methanol vapor to that of PAS. Rockley³ used the technique to obtain a highly quality spectrum of polystyrene. Low⁴ followed this by adapting the technique for use with a dispersive infrared spectrometer. It is clear, that the high throughput and multiplex advantages of FT-IR spectrometers offer the potential to make FT-IR PAS a routine, analytical technique for qualitative analysis.

The advantages of this technique over the more widely used KBr pellet technique for the study of composite are twofold.^{5,6} First, grinding of composite laminate into a powder of small particles and then proceeding to pressurize the KBr/powder mixture would alter the structure of the coupling agent and break and create bonds, thus forming new species not at all characteristic of the original composite laminate. Secondly, KBr (or any other alkali salt) is extremely hydrophilic. This would drastically alter the amount of water present in the composite. This effect would be manifested as a removal of water from the composite (present naturally in the sample) into the salt. The major advantages of PAS over other sampling techniques are the absence of sample preparation and the maintenance of sample integrity.⁷

1. ROCKLEY, M. G. *Fourier-Transformed Infrared Photoacoustic Spectroscopy of Solids*. Appl. Spectroscopy, v. 34, no. 4, 1980, p. 405-406.
2. BUSSE, G. and BULLEMER, B. *Use of the Opto-Acoustic Effect for Rapid Scan Fourier Spectroscopy*. Infrared Physics, v. 18, 1978, p. 255-256.
3. ROCKLEY, M. G. *The Photoacoustic Effect*. Chemical Physics Letters, v. 68, 1979, p. 455.
4. LOW, M. J. D. and PARODI, G. A. *Infrared Photoacoustic Spectroscopy of Solids and Surface Species*. Appl. Spectroscopy, v. 34, no. 1, 1980, p. 76-80.
5. ATAMAN, O. Y. and MAHK, H. B., Jr. *Applications of Photoacoustic Spectroscopy*. Appl. Spectroscopy Review, v. 13, no. 1, 1977.
6. DUYCKAERTS, G. *The Infra-red Analysis of Solid Substances - A Review*. Analyst, v. 84, 1959, p. 201-214.
7. GERSON, D. J., WONG, J. S. and CASPER, J. M. *Analytical Applications of Photoacoustic Detection to FTIR Spectroscopy*. American Laboratory, v. 16, no. 11, 1984, p. 63.

In this paper we will report the use of this technique to the study of fiber-reinforced epoxy resin composite laminates used in a variety of military structural applications.

EXPERIMENTAL

All infrared spectra were obtained on a Digilab Model 10M Fourier transform infrared spectrometer. Each spectrum was recorded in double precision at a resolution of 8 cm^{-1} for a total of 4096 scans. A reference helium-neon laser was used to calibrate the interferometer to allow a frequency accuracy of $\pm 5\text{ cm}^{-1}$. Data manipulations were done on a Nova 2 minicomputer from Data General.

A Digilab photoacoustic accessory was employed for all measurements. The moving mirror in the Michelson interferometer was translated with a velocity to 0.16 cm/s , which yielded modulation frequencies between 130 and 1300 Hz which gave a spectral range of 400 cm^{-1} to 4000 cm^{-1} . Drierite (Xenia, OH) was used in the sample compartment of the PAS accessory to remove residual water vapor in the cell. Figure 1 shows a schematic drawing of the sampling accessory.

Samples were either ground in a Spex freezer mill (Spex Industries, Edison, NJ) to obtain powders or cut up into chunks and placed in the cell. A comparison of spectra taken with chunks and after grinding revealed that no differences in the quality of the spectra could be detected. Carbon black (Cabot Corp., Billerica, MA) was used as a reference material.

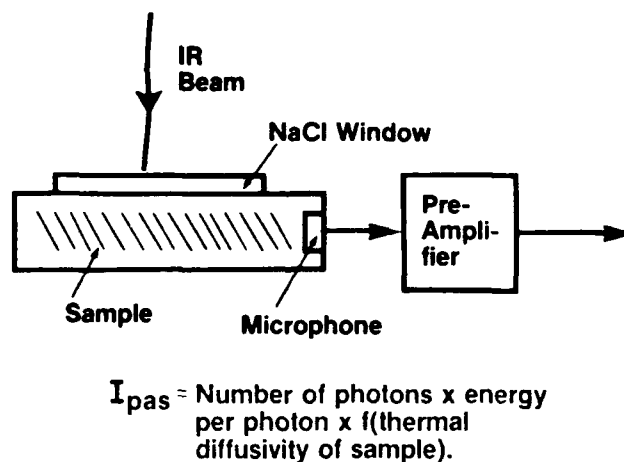


Figure 1. Schematic representation of the photoacoustic sample cell.

RESULTS AND DISCUSSION

State of Cure

Figures 2 and 3 show a DGEBA/anhydride resin system cured and post cured and analyzed using the PAS accessory. This system does not contain any glass fibers. The spectral differences are indicative of the state of cure of the resin system.

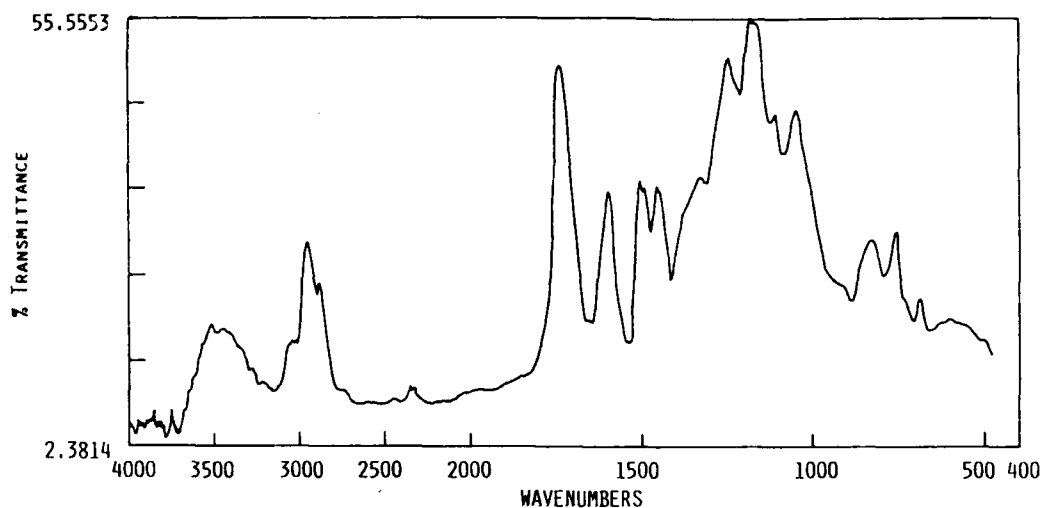


Figure 2. PAS-IR spectrum of cured DGEBA/anhydride resin system.

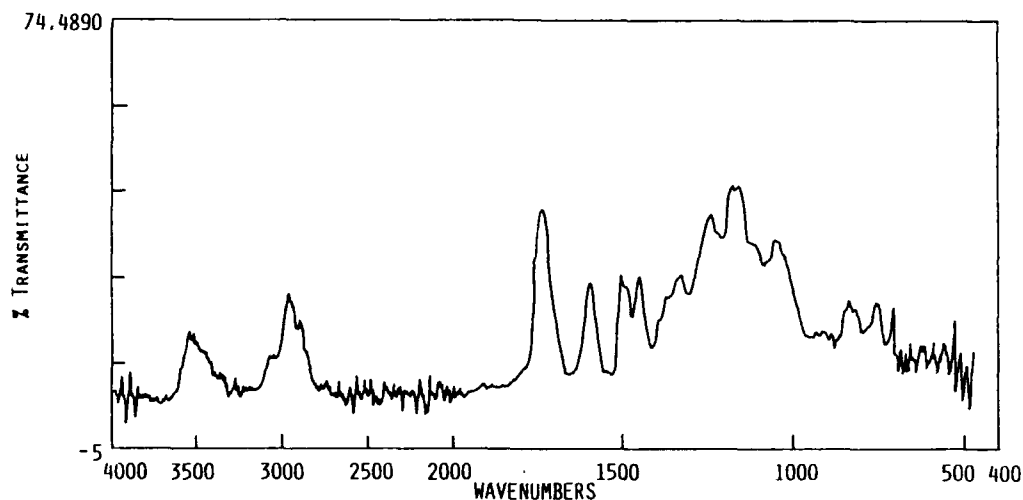


Figure 3. PAS-IR spectrum of post-cured DGEBA/anhydride resin system.

Figure 2 represents a normal cure for the resin system as recommended by the manufacturer. The spectrum is well resolved with many of the features of the cure clearly seen. Absorption bands at 1511 cm^{-1} and 1600 cm^{-1} remain invariant with reaction and can be used as internal standards. The remaining bands are characteristic of the curing reaction. Absorption bands can be seen at 3008 cm^{-1} [assigned to the $\nu_s(\text{CH}_2)$ of the epoxide ring] and at 910 cm^{-1} (epoxide group). They are residual epoxide bands, indicating that complete cure has not taken place. It is interesting that no absorptions are visible at 1858 cm^{-1} and 1780 cm^{-1} [$\nu_s(\text{C}=\text{O})$ and $\nu_s(\text{C}=\text{O})$ of the anhydride group, respectively]. This indicates that all the anhydride has reacted. Absorptions characteristic of the curing reaction can be seen by the formation of the ester group and nearby structures at 2963 cm^{-1} [$\nu_s(\text{CH}_2)$] adjacent to the ester group, at 1750 cm^{-1} [$\nu(\text{C}=\text{O})$ ester] and at 1250 cm^{-1} [$\nu(\text{C}=\text{O})$ of the ester].⁸

Figure 3 shows the DGEBA/anhydride system after post cure. In this spectrum all the same absorption bands are present as in the previous spectrum with the exception of the 915 cm^{-1} and 3008 cm^{-1} bands of the epoxide group. These bands are not seen due to the complete disappearance of the epoxide functionalities, indicating a complete cure cycle has occurred.

Glass Fiber-Reinforced Epoxy Laminate

Spectra were obtained of various types of glass-epoxy laminates in an attempt to elucidate the structures at the glass-coupling agent-epoxy interface. Spectral subtraction was used to eliminate the strong spectral features of the glass. Figure 4 shows the PAS-IR spectrum of the E-glass mat with a coupling agent deposited on its surface. The coupling is known to be γ -amino-propyltriethoxysilane (γ -APS). Absent from the spectrum are infrared maxima at 1595 cm^{-1} (NH_2 wag) and 1474 cm^{-1} (CH_2 wag) of the γ -APS, as well as an absorption band at 830 cm^{-1} . These IR bands are all well known IR absorption bands of γ -APS.

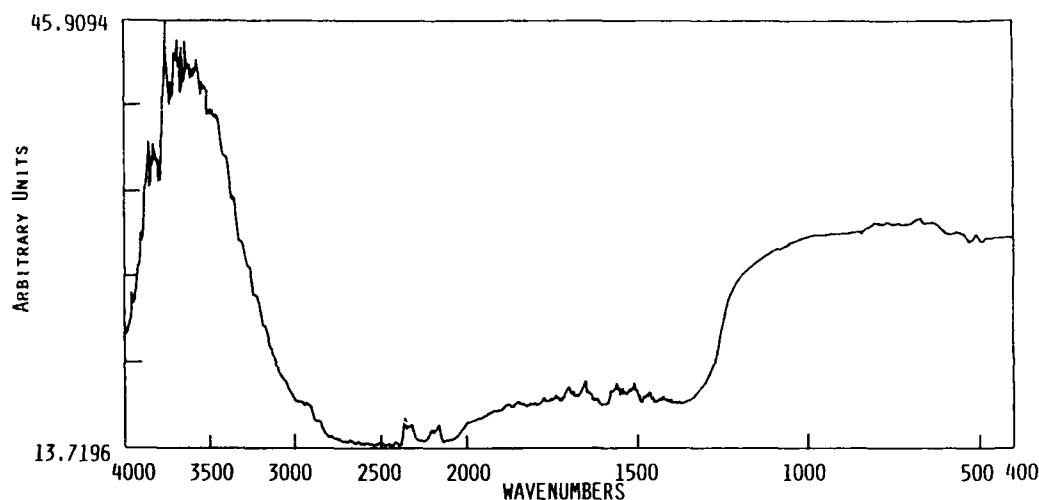


Figure 4. PAS-IR spectrum of E-glass mat with coupling agent deposited along surface.

It becomes clear that no IR absorbances due to the γ -APS can be detected. It can be assumed that the concentration of γ -APS on the glass mat is beyond the detection limits of the photoacoustic technique. It is approximated that the γ -APS is present in concentration levels, from 0.1% to 1.5% by weight. It is interesting to note that other IR sampling methods have been reported that are able to detect the γ -APS at these concentration levels.^{9,10}

Figure 5 shows a DGEBA/anhydride resin system cured with glass. The spectrum of the glass has been subtracted so only the spectrum of the resin system appears. It appears the laminate is completely cured, as no 910 cm^{-1} absorption band can be detected. In Figure 3, no absorptions are visible at 1858 cm^{-1} and 1780 cm^{-1} [ν_s (C=O) and ν_{AS} (C=O) of the anhydride, respectively]. This indicates all the anhydride curing agent has been reaction during the cure cycle. Formation of cross-linking C-O groups can be detected by the IR absorption bands at 1250 cm^{-1} . Figure 5 essentially shows the same spectral features as Figure 3.

9. CHIANG, C. H. and KOENIG, J. L. *Chemical Reactions Occurring at the Interface Epoxy Matrix and Aminosilane Coupling Agents in Fiber-Reinforced Composites*, Polymer Composites, v. 1, 1980, p. 88-92.
10. CHIANG, C. H. and KOENIG, J. L. *Fourier Transform Infrared Spectroscopic Study of the Adsorption of Multiple Amino Silane Coupling Agents on Glass Surfaces*, J. Colloid Interf. Sci., v. 83, no. 2, October 1981, p. 361-370.

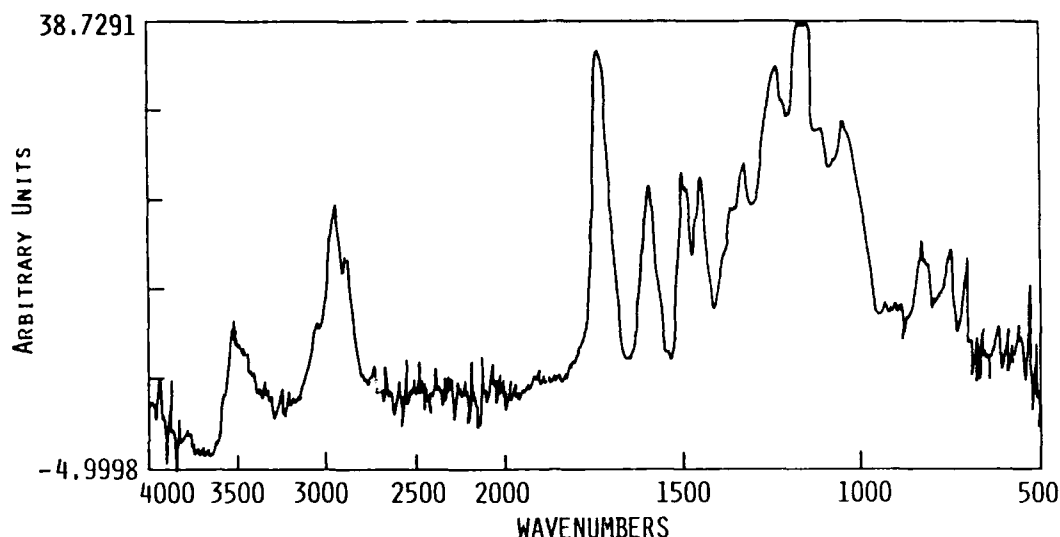


Figure 5. PAS-IR spectrum of a DGEBA/anhydride resin system with the spectrum of the glass subtracted.

Kevlar-Reinforced Laminates

Kevlar-reinforced composite laminates offer a different challenge to the PAS-IR technique. Kevlar is an extremely strong absorber of infrared radiation. In fact, it has a tendency to dominate the IR spectrum so much that the infrared spectrum of the resin is hardly seen. Figure 6 shows a spectrum of an amine-cured Epon 828 resin system reinforced with Kevlar. The strong absorption bands at 3325 cm^{-1} (asymmetric OH stretch) and 3420 cm^{-1} (symmetric OH stretch) can be seen at the high frequency end of the spectrum. More Kevlar absorptions appear at 1540 cm^{-1} and 1640 cm^{-1} (amide I and II bands), 1300 cm^{-1} , 1400 cm^{-1} , and 1110 cm^{-1} . These appear at strong, well defined IR absorptions. Infrared intensities of the resin system can be seen although they are not as pronounced as the intensities of the Kevlar. Absorptions in the $3100\text{ cm}^{-1} - 2800\text{ cm}^{-1}$ are characteristic of the aromatic CH stretches and aliphatic CH of the epoxy resin. Infrared maxima at 1510 cm^{-1} and 1605 cm^{-1} due to the aromatic ring stretch can clearly be seen. Absorptions in the $1150\text{ cm}^{-1} - 1250\text{ cm}^{-1}$ can be attributed to the C-O crosslinking group. No infrared absorptions appear at 910 cm^{-1} indicating a complete cure has occurred.

Dicy-Cured Epoxy Laminate

Figure 7 shows a spectrum of SP 250 resin system accelerated with Monuron, a chlorinated accelerator. The glass has not been subtracted as evidenced by the infrared absorption at 1100 cm^{-1} and a broad absorption at 3500 cm^{-1} . Here again absorptions at 1510 cm^{-1} and 1605 cm^{-1} are present. These are due to the aromatic ring stretches of the resin. Evidence for an incomplete cure is present by the small IR band at 910 cm^{-1} . This represents residual epoxide groups. The strong doublet at approximately 2240 cm^{-1} and 2260 cm^{-1} is due to unused Dicy. There appears to be a considerable amount of Dicy present in the laminate.

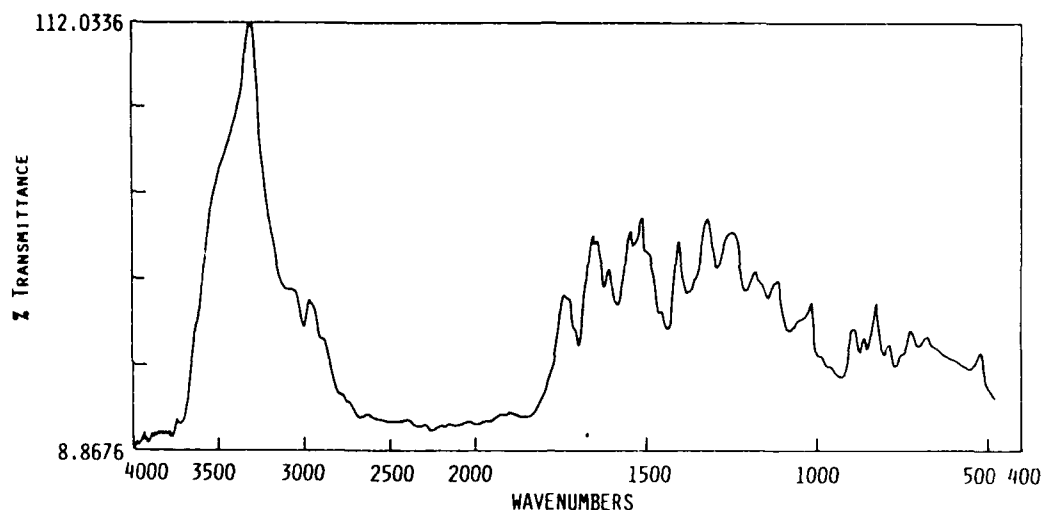


Figure 6. PAS-IR spectrum of Kevlar composite laminate.

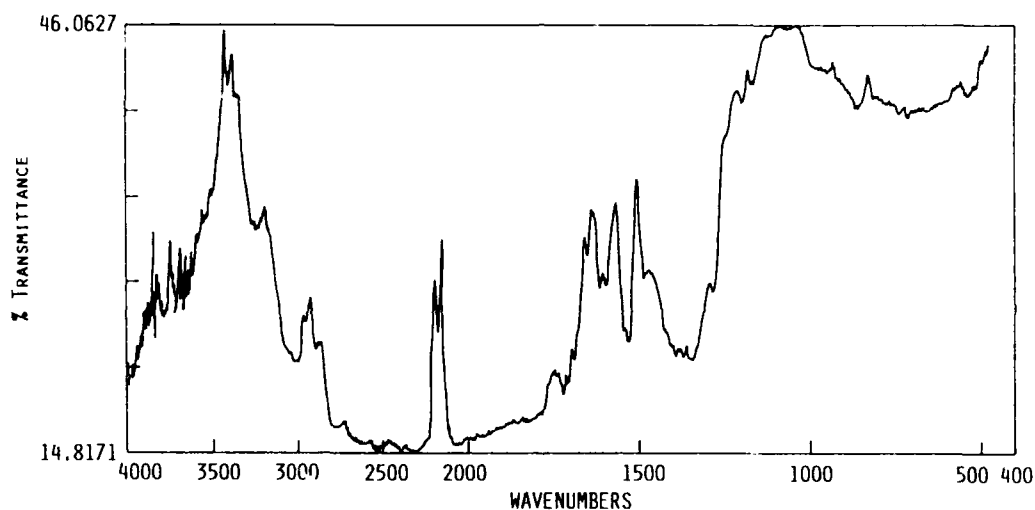


Figure 7. PAS-IR spectrum of SP 250 composite laminate.

CONCLUSIONS

Photoacoustic infrared spectroscopy has been used to evaluate various types of reinforced epoxy laminates. Information on the degree of cure and the type of reinforcing material has been derived. It has also been concluded that no information could be obtained on the nature of the glass-coupling agent-epoxy interface. The concentration level of the coupling agent (γ -APS) is too small to be detected by this technique.

The photoacoustic infrared spectroscopic technique does, however, offer the advantage of being an easy and reproducible method for obtaining high quality infrared spectra of the epoxy laminates. This case of use makes it an ideal sampling method for possible "in-field" testing of composite laminates.

DISTRIBUTION LIST

No. of Copies	To
1	Office of the Under Secretary of Defense for Research and Engineering, The Pentagon, Washington, DC 20301
	Commander, U.S. Army Laboratory Command, 2800 Powder Mill Road, Adelphi, MD 20783-1145
1	ATTN: SLCIS-IM-TL
	Commander, Defense Technical Information Center, Cameron Station, Building 5, 5010 Duke Street, Alexandria, VA 22304-6145
2	ATTN: DTIC-FDAC
1	Metals and Ceramics Information Center, Battelle Columbus Laboratories, 505 King Avenue, Columbus, OH 43201
	Commander, Army Research Office, P.O. Box 12211, Research Triangle Park, NC 27709-2211
1	ATTN: Information Processing Office
	Commander, U.S. Army Materiel Command, 5001 Eisenhower Avenue, Alexandria, VA 22333
1	ATTN: AMCLD
	Commander, U.S. Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD 21005
1	ATTN: AMXSY-MP, H. Cohen
	Commander, U.S. Army Electronics Research and Development Command, Fort Monmouth, NJ 07703
1	ATTN: AMDSD-L
1	AMDSD-E
	Commander, U.S. Army Missile Command, Redstone Arsenal, AL 35898
1	ATTN: AMSMI-RKP, J. Wright, Bldg. 7574
4	AMSMI-TB Redstone Scientific Information Center
1	AMSMI-RLM
1	Technical Library
	Commander, U.S. Army Armament, Munitions and Chemical Command, Dover, NJ 07801
2	ATTN: Technical Library
1	AMDAR-SCM, J. D. Corrie
1	AMDAR-QAC-E
1	AMDAR-LCA, Mr. Harry E. Pebly, Jr., PLASTEC, Director
	Commander, U.S. Army Natick Research and Development Center, Natick, MA 01760
1	ATTN: Technical Library
	Commander, U.S. Army Satellite Communications Agency, Fort Monmouth, NJ 07703
1	ATTN: Technical Document Center
	Commander, U.S. Army Tank-Automotive Command, Warren, MI 48090
1	ATTN: AMSTA-ZSK
2	AMSTA-UL, Technical Library
	Commander, White Sands Missile Range, NM 88002
1	ATTN: STEWS-WS-VT
	President, Airborne, Electronics and Special Warfare Board, Fort Bragg, NC 28307
1	ATTN: Library
	Director, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD 21005
1	ATTN: AMDAR-TSB-S (STINFO)
	Commander, Dugway Proving Ground, Dugway, UT 84022
1	ATTN: Technical Library, Technical Information Division

No. Of Copies	To
1	Commander, Harry Diamond Laboratories, 2800 Powder Mill Road, Adelphi, MD 20783 ATTN: Technical Information Office
1	Director, Benet Weapons Laboratory, LCWSL, USA AMCCOM, Watervliet, NY 12189 ATTN: AMSMC-LCB-TL
1	AMSMC-LCB-R
1	AMSMC-LCB-RM
1	AMSMC-LCB-RP
1	Commander, U.S. Army Foreign Science and Technology Center, 220 7th Street, N.E., Charlottesville, VA 22901 ATTN: Military Tech
1	Commander, U.S. Army Aeromedical Research Unit, P.O. Box 577, Fort Rucker, AL 36360 ATTN: Technical Library
1	Director, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, VA 23604-5577 ATTN: SAVDL-E-MOS (AVSCOM)
1	U.S. Army Aviation Training Library, Fort Rucker, AL 36360 ATTN: Building 5906-5907
1	Commander, U.S. Army Agency for Aviation Safety, Fort Rucker, AL 36362 ATTN: Technical Library
1	Commander, USACDC Air Defense Agency, Fort Bliss, TX 79916 ATTN: Technical Library
1	Commander, U.S. Army Engineer School, Fort Belvoir, VA 22060 ATTN: Library
1	Commander, U.S. Army Engineer Waterways Experiment Station, P. O. Box 631, Vicksburg, MS 39180 ATTN: Research Center Library
1	Technical Director, Human Engineering Laboratories, Aberdeen Proving Ground, MD 21005 ATTN: Technical Reports Office
1	Commandant, U.S. Army Quartermaster School, Fort Lee, VA 23801 ATTN: Quartermaster School Library
1	Naval Research Laboratory, Washington, DC 20375 ATTN: Dr. C. I. Chang - Code 5830
2	Dr. G. R. Yoder - Code 6384
1	Chief of Naval Research, Arlington, VA 22217 ATTN: Code 471
1	Edward J. Morrissey, AFWAL/MLTE, Wright-Patterson Air Force, Base, OH 45433
1	Commander, U.S. Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, OH 45433 ATTN: AFWAL/MLC
1	AFWAL/MLLP, M. Forney Jr.
1	AFWAL/MLBC, Mr. Stanley Schulman
2	Director, U.S. Army Materials Technology Laboratory, Watertown, MA 02172-0001 ATTN: SLCMT-IML
1	Author

U.S. Army Materials Technology Laboratory, Watertown, Massachusetts 02172-0001 EVALUATION OF EPOXY COMPOSITES USING PHOTOACOUSTIC FOURIER TRANSFORM INFRARED SPECTROSCOPY - James M. Sloan	AD UNCLASSIFIED UNLIMITED DISTRIBUTION Key Words	U.S. Army Materials Technology Laboratory, Watertown, Massachusetts 02172-0001 EVALUATION OF EPOXY COMPOSITES USING PHOTOACOUSTIC FOURIER TRANSFORM INFRARED SPECTROSCOPY - James M. Sloan	AD UNCLASSIFIED UNLIMITED DISTRIBUTION Key Words
Technical Report MTL 86-29, July 1986, 8 pp - illus, D/A Project IT161101A91A	Composite materials Epoxy resins Infrared spectroscopy	Technical Report MTL 86-29, July 1986, 8 pp - illus, D/A Project IT161101A91A	Composite materials Epoxy resins Infrared spectroscopy
Fourier transform infrared spectroscopy (FT-IR) using a photoacoustic sampling cell has been used to obtain high quality infrared spectra of various fiber-reinforced epoxy composites and the corresponding resin matrixes. Photoacoustic spectroscopy (PAS) offers the advantages of having little or no sample preparation for high quality spectra to be obtained and no alignment of the infrared incident beam is necessary. This makes PAS an ideal sampling method for "in-field" testing of composite laminates. The spectra revealed information on the degree of cure of the resin system by monitoring the 915 cm ⁻¹ absorption band and the type of reinforcement material used (glass or Kevlar).		Fourier transform infrared spectroscopy (FT-IR) using a photoacoustic sampling cell has been used to obtain high quality infrared spectra of various fiber-reinforced epoxy composites and the corresponding resin matrixes. Photoacoustic spectroscopy (PAS) offers the advantages of having little or no sample preparation for high quality spectra to be obtained and no alignment of the infrared incident beam is necessary. This makes PAS an ideal sampling method for "in-field" testing of composite laminates. The spectra revealed information on the degree of cure of the resin system by monitoring the 915 cm ⁻¹ absorption band and the type of reinforcement material used (glass or Kevlar).	
U.S. Army Materials Technology Laboratory, Watertown, Massachusetts 02172-0001 EVALUATION OF EPOXY COMPOSITES USING PHOTOACOUSTIC FOURIER TRANSFORM INFRARED SPECTROSCOPY - James M. Sloan	AD UNCLASSIFIED UNLIMITED DISTRIBUTION Key Words	U.S. Army Materials Technology Laboratory, Watertown, Massachusetts 02172-0001 EVALUATION OF EPOXY COMPOSITES USING PHOTOACOUSTIC FOURIER TRANSFORM INFRARED SPECTROSCOPY - James M. Sloan	AD UNCLASSIFIED UNLIMITED DISTRIBUTION Key Words
Technical Report MTL 86-29, July 1986, 8 pp - illus, D/A Project IT161101A91A	Composite materials Epoxy resins Infrared spectroscopy	Technical Report MTL 86-29, July 1986, 8 pp - illus, D/A Project IT161101A91A	Composite materials Epoxy resins Infrared spectroscopy
Fourier transform infrared spectroscopy (FT-IR) using a photoacoustic sampling cell has been used to obtain high quality infrared spectra of various fiber-reinforced epoxy composites and the corresponding resin matrixes. Photoacoustic spectroscopy (PAS) offers the advantages of having little or no sample preparation for high quality spectra to be obtained and no alignment of the infrared incident beam is necessary. This makes PAS an ideal sampling method for "in-field" testing of composite laminates. The spectra revealed information on the degree of cure of the resin system by monitoring the 915 cm ⁻¹ absorption band and the type of reinforcement material used (glass or Kevlar).		Fourier transform infrared spectroscopy (FT-IR) using a photoacoustic sampling cell has been used to obtain high quality infrared spectra of various fiber-reinforced epoxy composites and the corresponding resin matrixes. Photoacoustic spectroscopy (PAS) offers the advantages of having little or no sample preparation for high quality spectra to be obtained and no alignment of the infrared incident beam is necessary. This makes PAS an ideal sampling method for "in-field" testing of composite laminates. The spectra revealed information on the degree of cure of the resin system by monitoring the 915 cm ⁻¹ absorption band and the type of reinforcement material used (glass or Kevlar).	